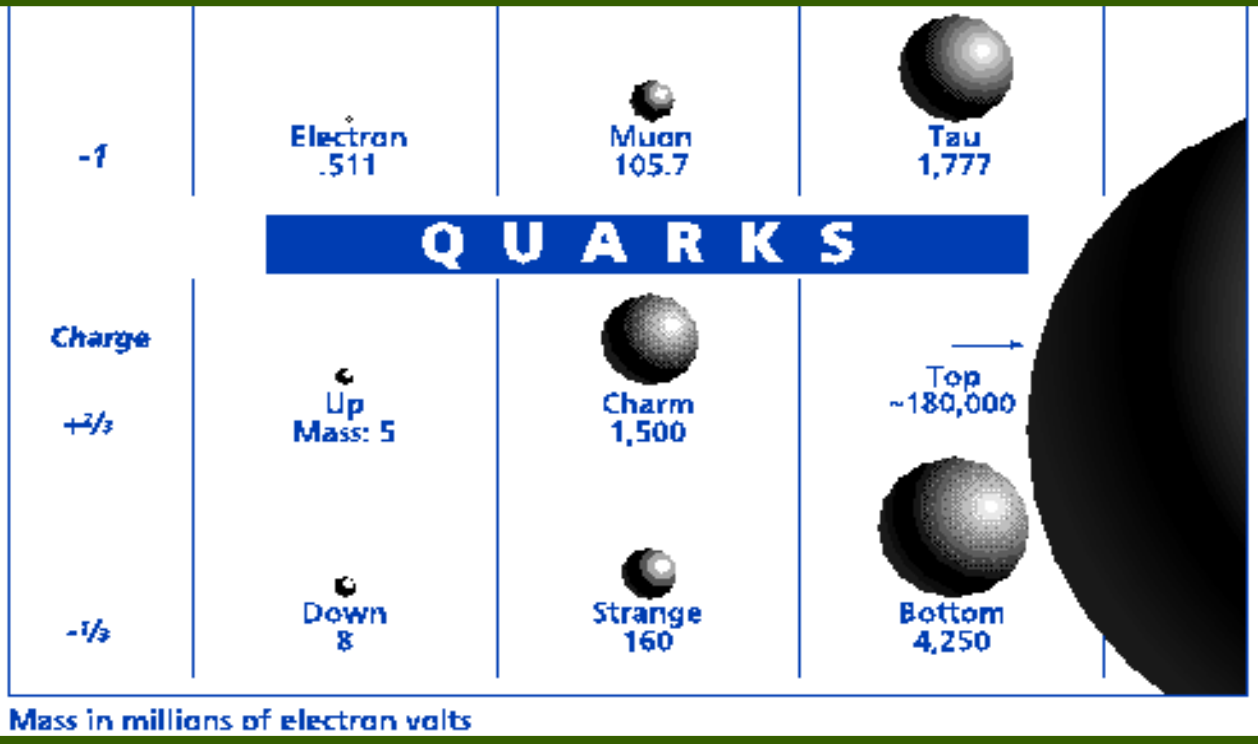
Measurements of top quark properties in ttbar events at D0



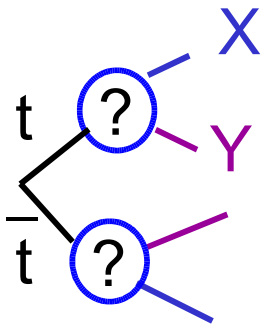
- Top properties
- Recent Run I results
- RunII: work in progress
- Conclusion

Martijn Mulders
Fermilab

PHENO 2004, Madison WI, Apr 27, 2004

Top Properties in ttbar events

- Top pair production at Tevatron: first observed in Run I, now re-established in Run II (see previous talk, Kristian Harder)
- Unique laboratory to study top quark properties / interactions



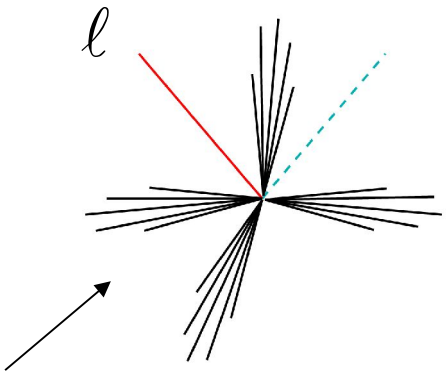
In the SM:
X=W 100% of the time
Y=b ~100% of the time ($|V_{tb}|$~1)
$g_{Wtb} \propto |V_{tb}|$ (V-A)

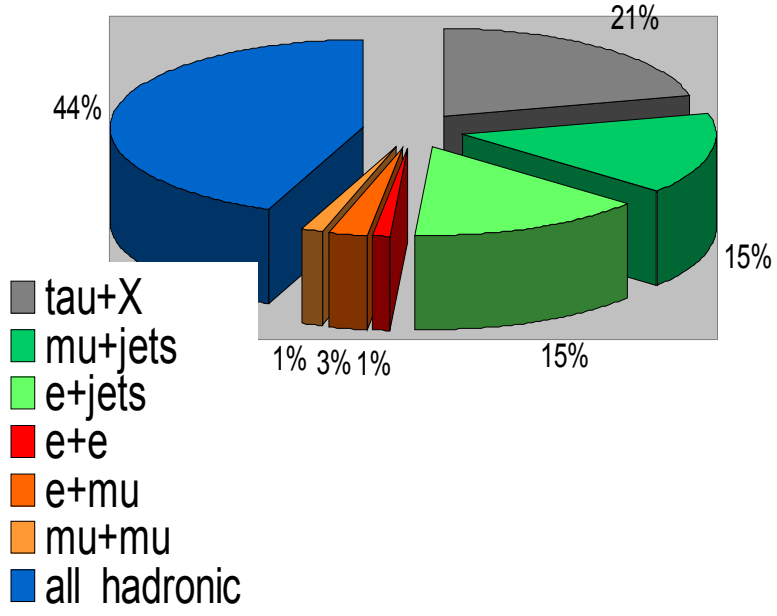
Top mass
B(t→Wb)
$|V_{tb}|$
W helicity
Top polarization
Anomalous couplings
Spin correlations
Rare decays
Top width
Top charge
…

- Recent updates using Run I data set:
  - --> Improved Run I mass & W helicity measurement
- Further improvements: Use more statistics & better detectors: Run II

Measuring Top Properties ...

- Challenge: complex events require good understanding of all aspects of event reconstruction (jets, electrons, muons, 'missing energy', b-tag, trigger biases, object resolutions) and partly rely on Monte Carlo simulation
- Large backgrounds vs low statistics, depending on decay channel





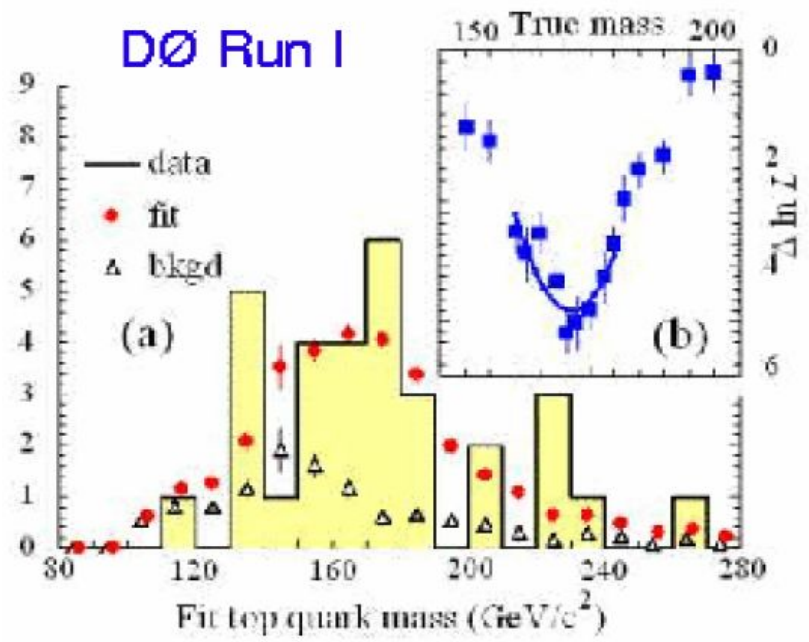
- Lepton+jets channel: 12 possible permutations to assign the two b-jets and two light quark jets (from W decay) to 4 jets (fewer if 1 or 2 jets are b-tagged)

Top Mass in lepton+jets channel

- Previous published D0 measurement [PRD 58 (1998), 052001]:

  m_t = 173.3 +- 5.6 (stat) +- 5.5 (syst) GeV

- Pre-selection:
  - Isolated, high-p_T lepton
  - >= 4 jets
  - Large missing E_T
- 91 events selected, 125 pb^{-1}
- 'Template' method to extract mass:
  - Use mass from lowest- χ^2 solution from constrained kinematic fit
  - Topological discriminant used to separate signal and background
  - Fit observed 2D distribution of mass and discriminant to MC 'templates' for different values of generated Top mass



New Run I top mass measurement

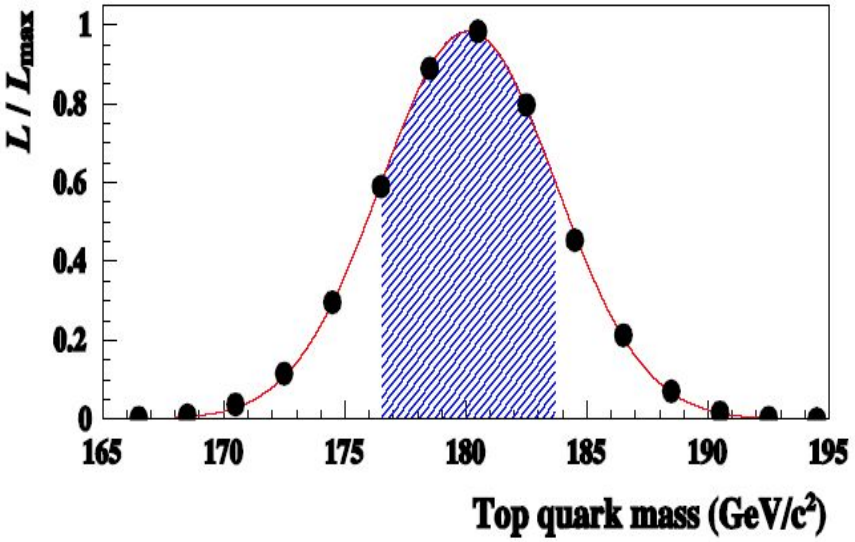
- Capture full ambiguity of l+jets event in event-by-event likelihood:

$$P(x, M_t) = \frac{1}{\sigma(x)} \int d\sigma(y, M_t)\, dq_1\, dq_2\, f(q_1)\, f(q_2)\, W(y, x)$$

- $P(x, M_t)$: Mass-dependent, reconstructed 4-vectors
- $d\sigma(y, M_t)$: Differential Xsec (LO Matrix element + phase space)
- $f(q_1)\, f(q_2)$: PDF's
- $W(y, x)$: Transfer function Relating partonic Variables to Measured quantities

- Event probability: $P(x; c_1, c_2, M_t) = c_1 P_{t\bar{t}}(x; M_t) + c_2 P_{\text{bkgd}}(x)$
- Background (85% W+jets) probability from VECBOS LO Matrix Element
- Sum all 12 possible jet assignments
- Only 4-jet events,

  and require Pbkgd < 10^{-11}
  - 22 events remain
- Mt = 180.1 +- 3.6 (stat) +- 3.9 (syst) GeV
- Accepted for publiciation in Nature



Effect on Higgs mass prediction

- New Tevatron top mass combination
- Indirect prediction for Higgs boson mass via SM fit shifts to higher value:

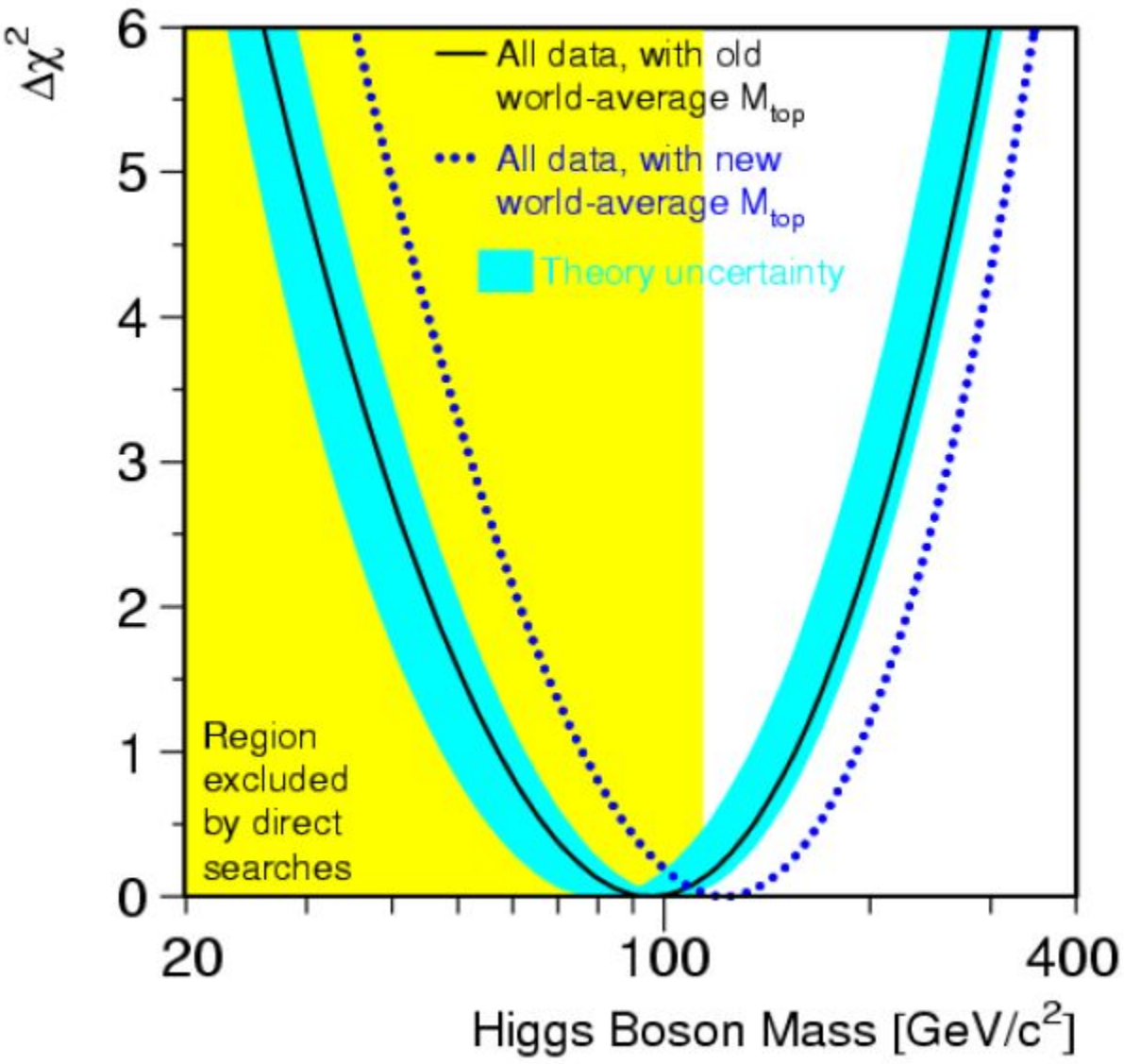
Old:

$$M_{top} = 174.3 \pm 5.1 \text{ GeV}$$
$$\log M_H = 1.98^{+0.21}_{-0.22}$$
$$M_H = 96^{+60}_{-38} \text{ GeV}$$
$$\text{or} < 219 \text{ GeV (95\% CL)}$$

New:

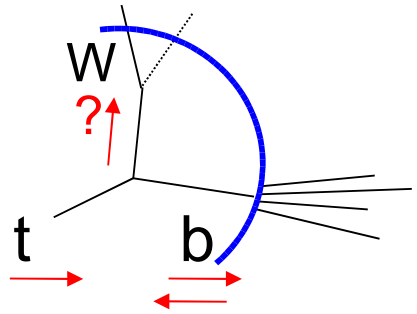
$$M_{top} = 178.0 \pm 4.3 \text{ GeV}$$
$$\log M_H = 2.07^{+0.20}_{-0.21}$$
$$M_H = 117^{+67}_{-45} \text{ GeV}$$
$$\text{or} < 251 \text{ GeV (95\% CL)}$$

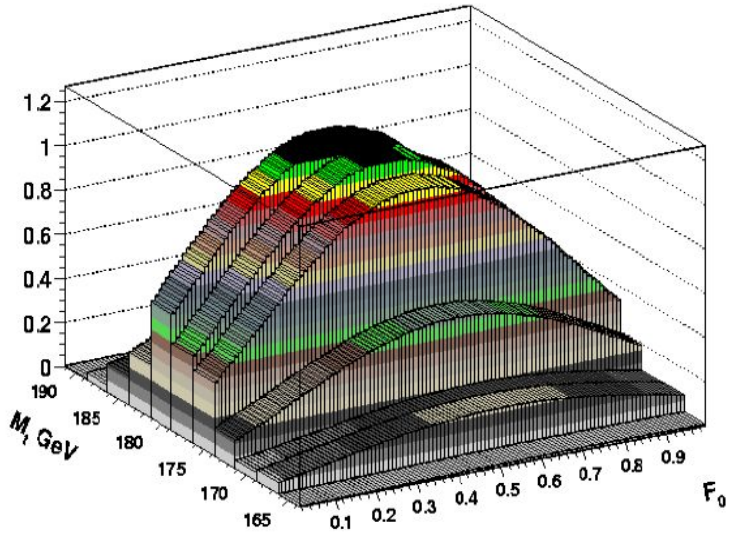
(Procedure as in hep-ex/0312023!)



ME method also works for W helicity

- Top decays before hadronization can occur
- Spin information transferred to decay products (Wb)--> with V-A current in SM, polarization of W is:
  - 70% longitudinal (F_0)
  - 30% left-handed (F_-)



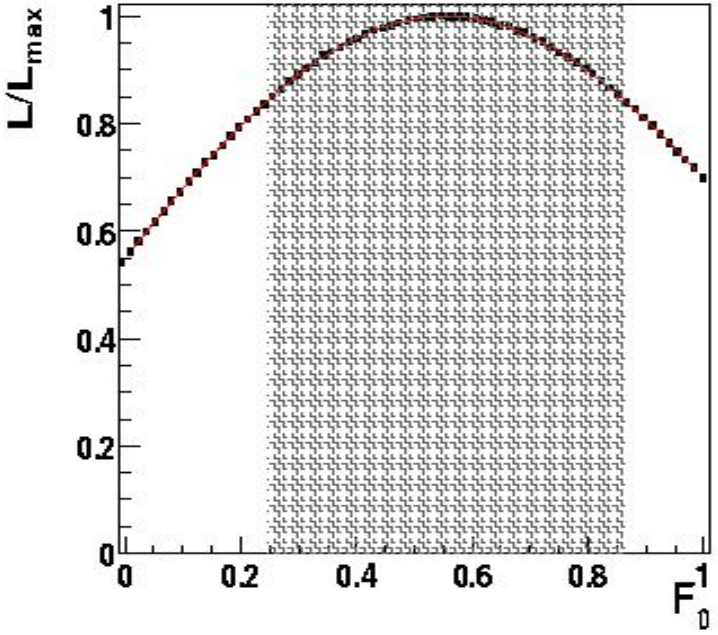


- Angular distribution of W decay products in W rest frame probes this mixture
- Use same Matrix Element based event probabilities --> maximize likelihood as a function of F_0 in the matrix elements
- D0 preliminary:

F_0 = 0.56+-0.32 (stat)+-0.04 (syst)

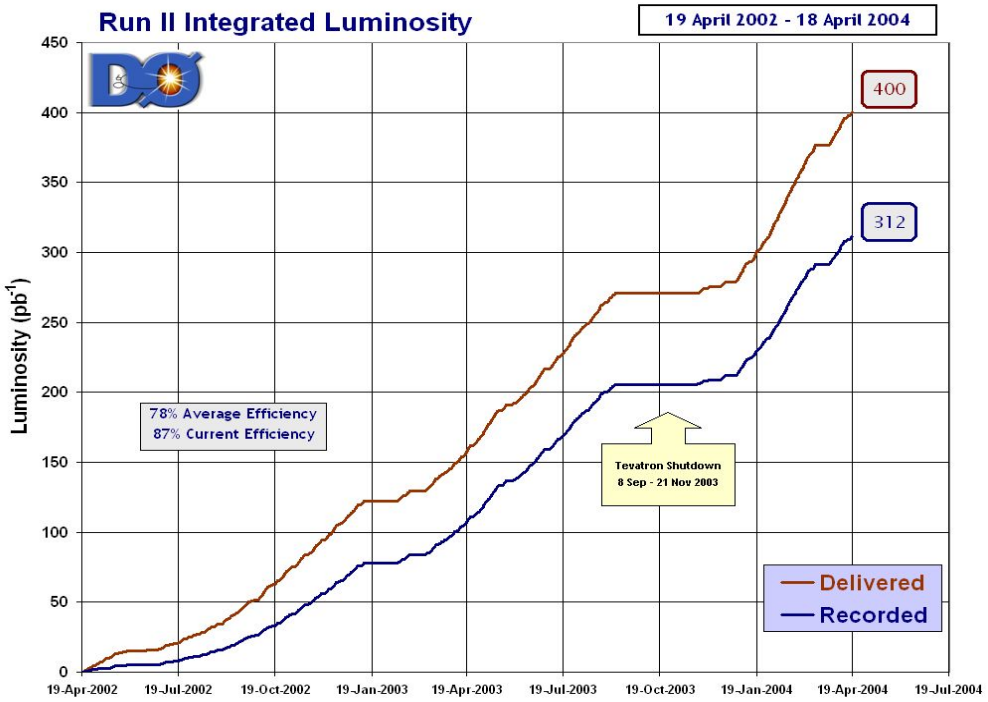
nice physics results with only 22 events ...

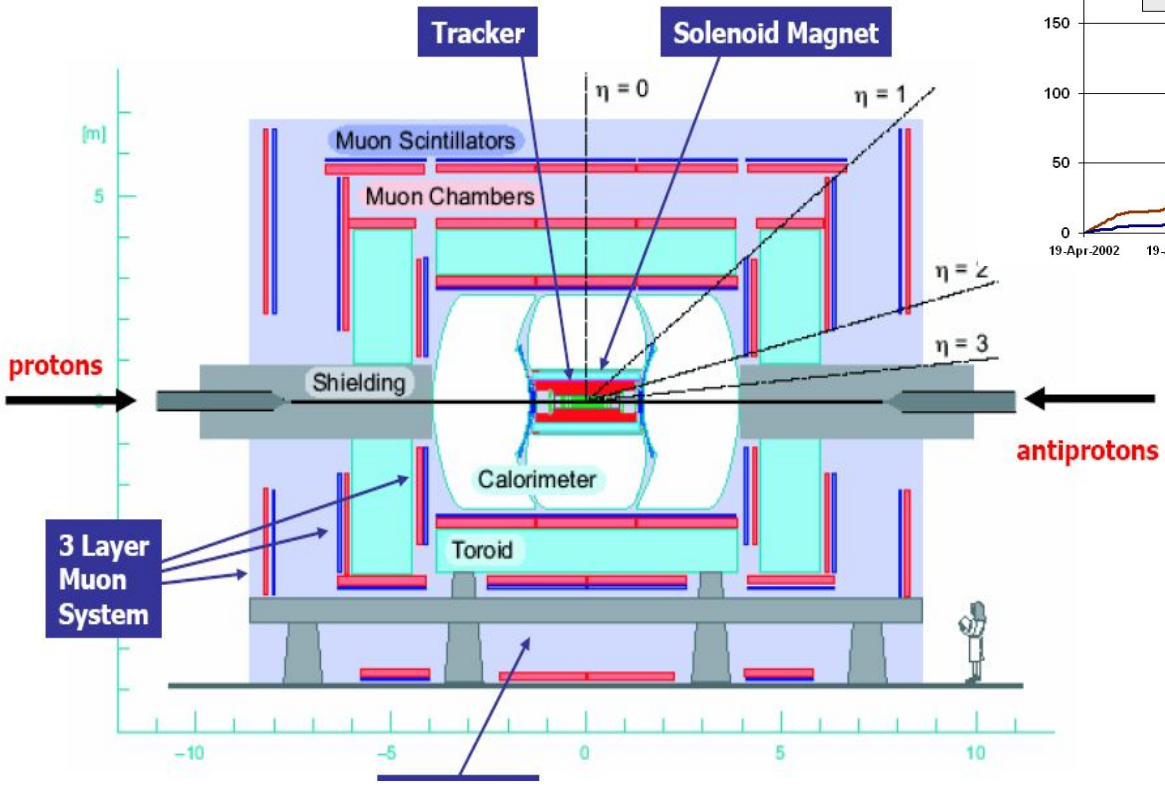
DØ Preliminary



Run II

- More Luminosity!!
  - > 400 pb^{-1} delivered
  - > 300 pb^{-1} on tape





- RunII D0 detector upgrade:
  - New inner tracker --> improved tracking (e.g. b-tagging, ..)
  - Improved muon acceptance / resolution

Top mass: Run II analyses in progress

- Start from data sample and event selections used in ttbar cross-section analyses (see talk by Kristian Harder)

- Lepton + jets channel:
  - similar to Run I Template method
  - similar to Run I Matrix Element method
  - New: "Ideogram" analysis is combination of both...

- Di-lepton channel:
  - similar to Run I neutrino weighting analysis
  - similar to Run I matrix-element weighting analysis

  [see: PRD 60 (1999), 052001]

Run II "Ideogram" method

(Inspired by DELPHI W mass measurement in WW-->qqqq channel)

- 'Standard' lepton + jets event selection:
  - >= 4 jets, high p_T isolated lepton, missing E_T

    (use 4 leading jets in kinematic fit)
- Combination of Template and Matrix Element approach:
  - Use constrained kinematic fit as in Template method --> 12 solutions with fitted mass $\mathbf{m_i}$, error on mass σ_i , and χ^2_i (--> 24 when allowing for 2 solutions of neutrino momentum along beam direction)
  - Construct an analytical event likelihood as in Matrix Element method, taking into account all jet combinations and the probability that an event is background

Run II "Ideogram" method (II)

- Calculate analytical event likelihood as:

$$L_{\text{event}}(m_{\text{top}}, P_{\text{samp}}) = \mathrm{P}(x)\cdot\mathbf{S}(x, m_{\text{top}}) + (1-\mathrm{P}(x))\cdot\mathbf{B}(x)$$

$$\mathrm{P}(x) = \mathrm{P}(D, P_{\text{samp}})$$

integration in 1 dimenson

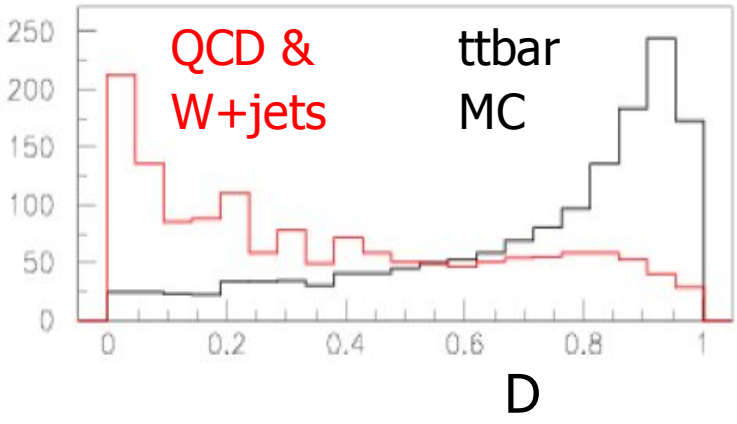
$$\mathbf{S}(x, m_{\text{top}}) = \sum_{i=1}^{24} w_i \cdot \int \mathbf{d}\, m'\, \mathbf{G}(m', m_i, \sigma_i)\cdot\mathbf{BW}(m', m_{\text{top}})$$

$$\mathbf{B}(x) = \sum_{i=1}^{24} w_i \cdot \mathbf{BG}(m_i) \qquad w_i = \exp(-\chi_i^2/2)$$

- Event purity P depends on topological D variable, and average sample purity P_samp (--> let P_samp float freely in fit)
- 'Matrix Element' is 1-dimensional Breit-Wigner BW(m', m_top)
- Obtain background mass spectrum BG(m') from MC

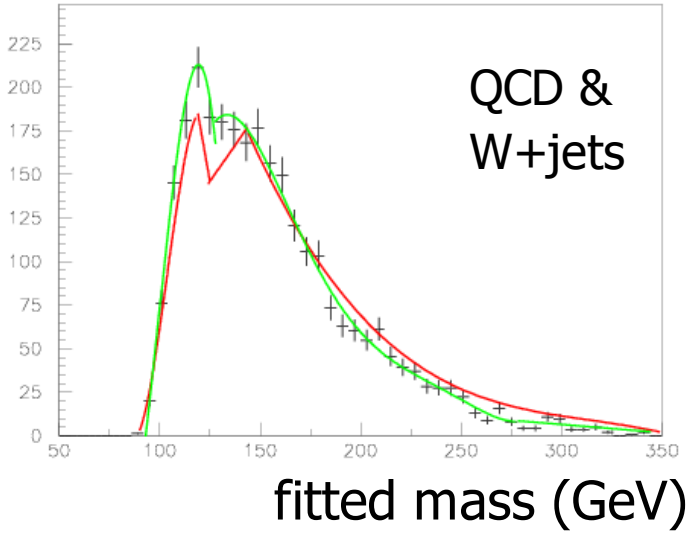
Run II "Ideogram" method (III)

- Use topological likelihood discriminant D :

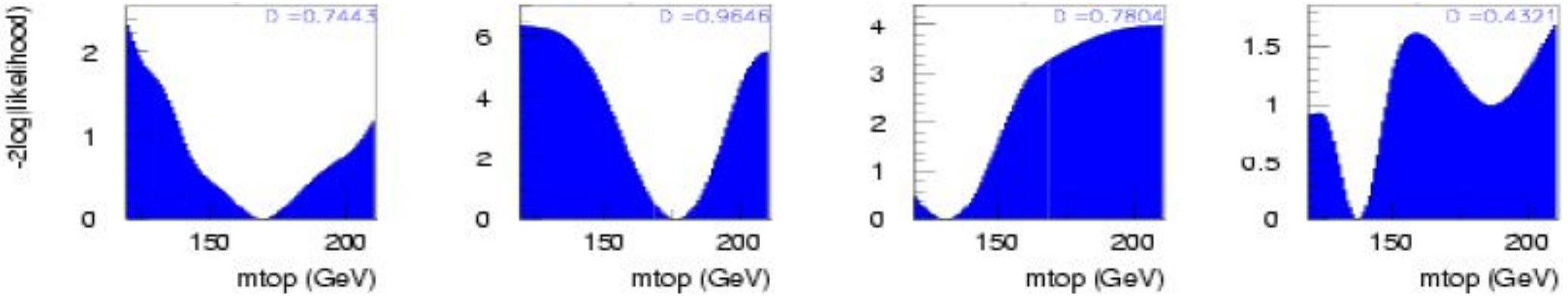


mu+jets

- Extract expected background mass distribution from MC:



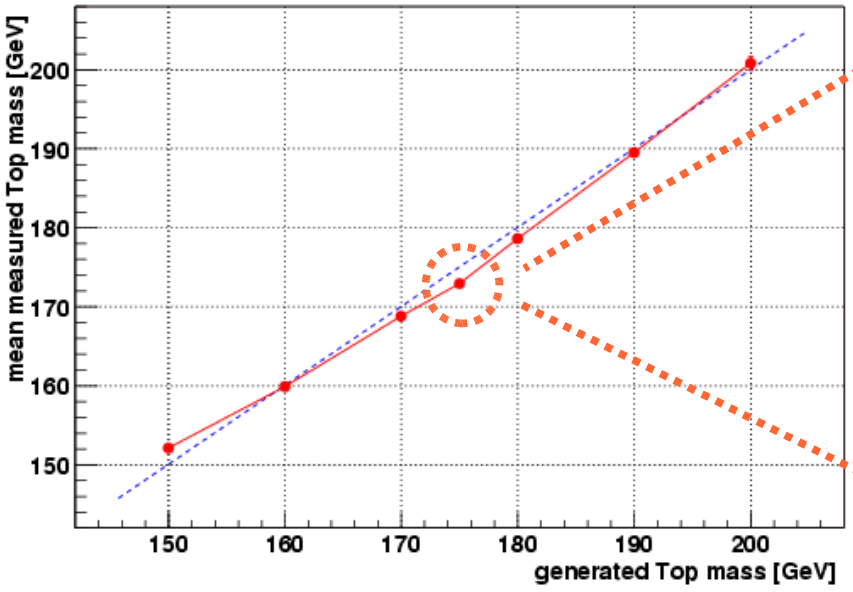
- Examples of -2 log (event likelihoods), for fixed value of P_samp :

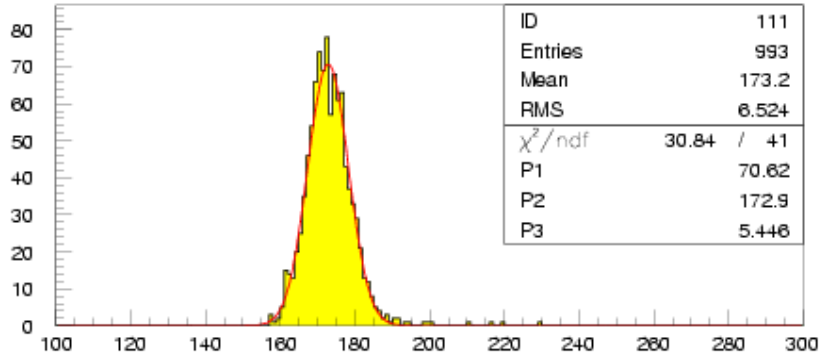


Run II "Ideogram" method (IV)

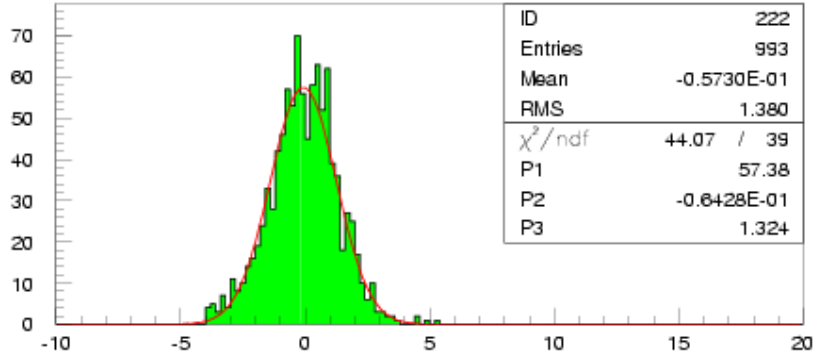
- Combined likelihood = product event likelihoods --> extract mass M_t and sample purity P_{samp}
- Use MC to calibrate the mass offset
- Use MC for ensemble tests (pseudo experiments) to check statistical properties

e+jets channel, ~ 150 pb-1:





fitted sample mass (GeV)



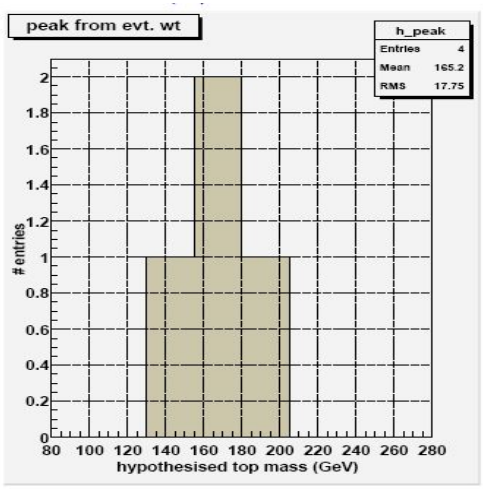
pull

Status of l+jets mass analyses

- All 3 analyses have been tested extensively and show excellent performance on 'MC' --> 'MC' is our best representation of the data, using full MC simulation with added smearing to reproduce resolutions seen in data and corrections for object ID efficiencies (and data with reversed lepton isolation cuts to represent QCD background)
- Aplied to ~150 pb^{-1} of Run II data
- Currently working on further understanding systematic issues:
  - jet energy scale
  - agreement between data and MC, background model
- Soon: include information from b-tagging to increase signal purity and reduce combinatorial background

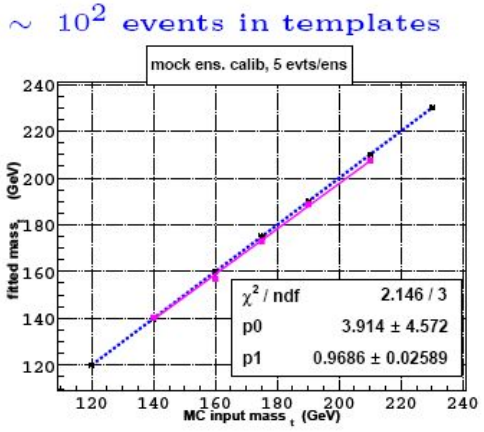
Run II di-lepton mass analyses

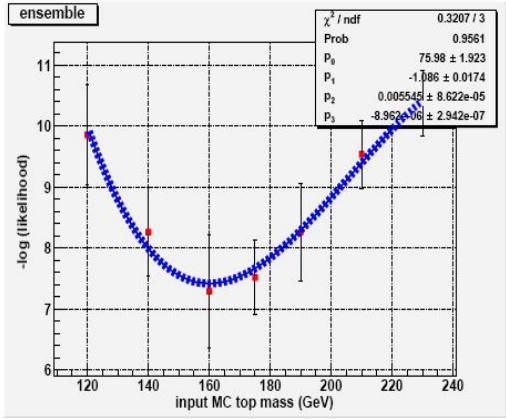
- Di-lepton channel: two neutrino's --> fewer constraints
- 1) similar to Run I publication; neutrino weighting method
  - Dalitz & Goldstein, Kondo
  - use e, μ, 2 leading jets, missing $p_{T,}$ assume m_t
  - find t/tbar momenta consistent with observed event
  - assign weight $W=f(x)f(x)p(E_e|m_t)p(E_\mu|m_t)$
  - sum over up to eight possible solutions
  - use m_t for with largest Σ W as mass estimator --> compare distribution of mt estimators with MC 'Templates' to fit final mass



- 2) Run I matrix-element weighting

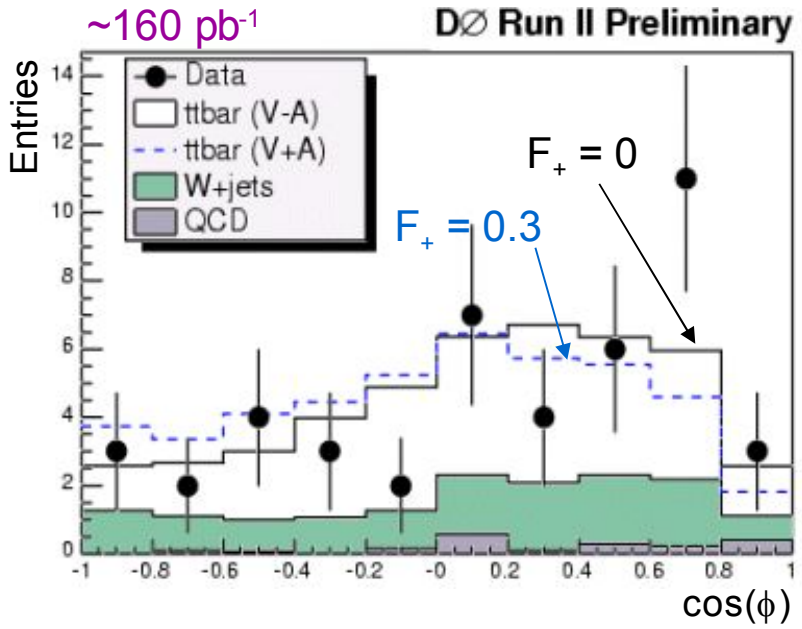
techique: assume neutrino eta, solve event kinematics, compare weights with 'Templates', fit S/B and mt





W Helicity in Run II

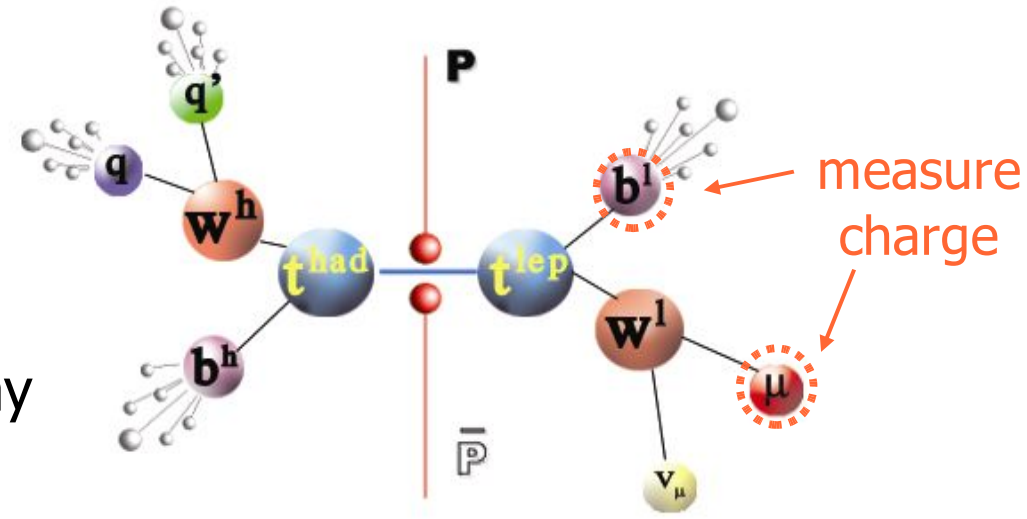
- Run II update of W helicity measurement in progress
- Uses lepton + jets channel --> choose correct jet assignment using kinematic fit and look at angle φ between lepton and b-quark
- Uses b-tagging to increase signal purity and reduce combinatorial background (untagged analysis also underway)
- Data fitted to MC templates in cos(φ) distribution corresponding to different values of F_+ (assume F_0 SM-like)
- Simultaneous determination of F_+ and signal and background fractions (constrained by a topological likelihood)



Analysis being optimized

Other Run II analyses in progress

- 1) Measurement of charge of the top quark (using SLT b-tagging)
  - Get charge lepton
  - Get charge b-jet (using Soft Lepton Tag)
  - Choose assignment b-jet to hadronic / leptonic decay top using kinematic fit



- 2) Branching ratio R = B(t-->Wb) / B(t-->Wq) using SVT b-tagging
  - Count ttbar events with 0,1 or 2 b-tags, using secondary vertex tagging (SVT)

Conclusions

- D0 has a very active Top Properties program in place
- New Run I top mass and W helicity result !
- Next: do even better with Run II data

- Several Run II top mass & W helicity analyses in advanced state
- Other analyses started...
- Soon more statistics and use of b-tagging

- Stay tuned !!